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HYDROCARBON CONSTITUENTS OF T-56 COMBUSTOR EXHAUST

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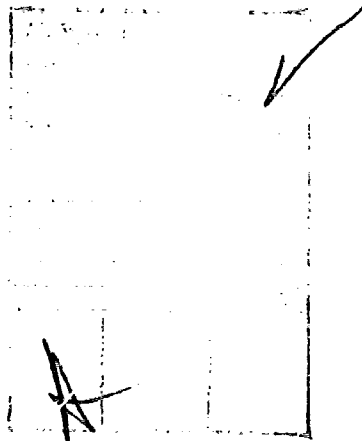Project Scientist

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Cryogenic sampling was used to sample hydrocarbon exhaust from a T-56 turbine
engine combustor under conditions simulating idle power of several different
aircraft. Parameters studied were fuel type--JP4, JP5, and JP8--and the combustor
operating pressure--15, 33, 50, and 75 psig. Samples were analyzed with a gas
chromatograph-mass spectrometer-data system which separated 148 compounds; the
hydrocarbon content of the exhaust was inversely proportional to the inlet
pressure and directly proportional to the boiling point and density of the fuel
type.

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HYDROCARBON CONSTITUENTS OF T-56 COMBUSTOR EXHAUST

INTRODUCTION

To provide baseline data for assessing the biomedical impact of aircraft operations, the United States Air Force School of Aerospace Medicine (USAFSAM) initiated a cooperative effort with the Air Force Aero Propulsion Laboratory (AFAPL) in late 1972 to conduct sampling and analysis of turbine engine exhaust hydrocarbons from the AFAPL single-combustor test facility. The approach involved both grab sampling of exhaust, in pressurized containers, and long-term, online exhaust sampling with the USAFSAM multistage cryogenic trapping system. Collected samples were analyzed with a coupled gas chromatograph-mass spectrometer-data (GC-MS-data) system. A preliminary sampling test was conducted in May 1973 to determine feasibility of exhaust cryotrapping and to establish analytical methodology for identifying individual hydrocarbon compounds (3).

This report details results from the second sampling test, conducted in January 1974, to identify and quantitate hydrocarbon emissions from the T-56 combustor as a function of fuel type and combustor operating pressure. The T-56 engine is of the turbine-driven propeller type (turboprop) used on the Air Force C-130 transport aircraft.

EXPERIMENTAL

Test Parameters

The AFAPL combustor rig used for this study (Fig. 1) consisted of a single T-56 series I combustor installed in equipment simulating the airflow characteristics in the actual engine. Compressors and a nonvitiated heating system supplied air at appropriate temperatures, pressures, and flow rates for the experiment.

Rather than perform the entire experiment at combustor inlet conditions corresponding to T-56 engine idle, a number of temperature/pressure conditions simulating idle operation of a wide range of engine types were tested. Table 1 lists the combustor operating conditions for each test. The lowest temperature condition tested involved 93°C inlet temperature and approximately 15 psig pressure. This corresponds to a number of Air Force engines, such as the J-85, which have overall pressure ratios. The midtemperature setting was at about 166°C, and 33 psig, corresponding to the conditions of many moderate-pressure ratio engines (1). Finally the high-temperature condition of 204°C and 50 psig simulates many newer high-pressure-ratio engines, like the F-101 and F-100. Table 2 lists typical military engines and their respective idle-pressure ratios (4).
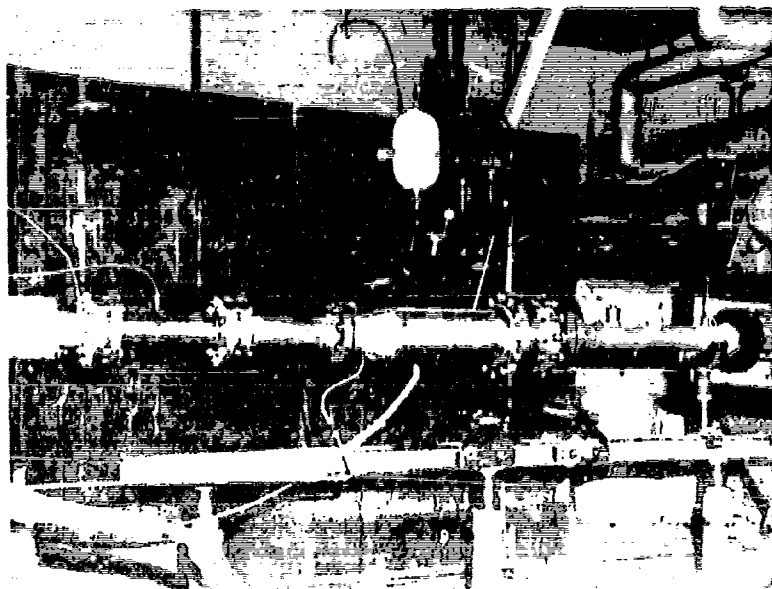
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Figure 1. Combustor Test Rig.

The fuels used were JP4, JP5, and JP8. The present Air Force jet fuel, JP4, was tested at all the conditions described above. The current Navy jet fuel, JP5, and JP8, a fuel similar to that used by commercial airlines and occasionally by Air Force aircraft, were tested at an operating pressure of 3.2 atm.

Sampling

The combustor exhaust was continuously sampled from a 5-point sampling rake located approximately 10.2 cm (4 in) aft of the combustor liner exit. Hot exhaust gas (121°C) was delivered, via electrically heated 6.4 mm (1/4-in) OD stainless steel tubing to online instrumentation for continuous analysis of CO, CO_2, NO_x, and total hydrocarbons (THC), as well as to two 3-stage cryogenic sampling systems. Cryogenic sampling was initiated after combustor operation had stabilized, and was continued until flow stopped because of ice blockage in the CO_2 trap. Nominal sampling time ranged from 60 to 90 minutes. The pressurized grab samples were obtained directly from the sample line at essentially the combustor operating pressure. The pressurized samples were collected in the 10 minutes prior to obtaining the integrated 60-90 minute sample with the cryogenic sampling system and from the same sample line.

TABLE 1. SINGLE-COMBUSTOR RIG OPERATING CONDITIONS

Nominal Power Setting	Rig Pressure psig	Inlet Temp. °C	Fuel/Air Wt. Basis	Fuel
Preliminary	75	93	.0076	JP4
Moderate PR[a] Simulated idle	33	166	.0070	JP4
Low PR Simulated idle	15	93	.0073	JP4
Moderate PR Simulated idle	33	169	.0083	JP5
High PR Simulated idle	50	204	.0079	JP4
Moderate PR Simulated idle	33	164	.0071	JP4
Moderate PR Simulated idle	33	166	.0072	JP8
No fuel flow (Background)	33	---	-----	---

[a]Pressure ratio.

TABLE 2. AIR FORCE TURBINE ENGINES

Engine	Aircraft	Idle-pressure ratio
J-85	T-38, F-5A	1.49
J-79	F-104, F-4D, F-4E	2.55
J-57	B-52F-G, F-100, F-101, KC-135	2.60
J-52	C-9	2.80
TF-39	C-5A	3.05
T-56	C-130	3.50
TF-30	F-111	3.56
F-101	B-1	4.0
F-100	F-15	4.4

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The cryogenic sampling system is shown schematically in Figure 2. The sample gas was passed through a flow meter at 500 cc/min (measured at 21.1°C and 760 Torr) into the first trapping cylinder (maintained at 0°C with ice water), through a heated inlet into the second cylinder (maintained at -78°C with pulverized dry ice), throu.! the final cylinder (maintained at -175°C with liquid nitrogen), and then exhausted to ambient. Two unique features of the cryotrap system are the heated inlet in the -78°C trap to minimize ice formation and a gaseous nitrogen flush in the -175°C trap matrix to prevent oxygen condensation (2).
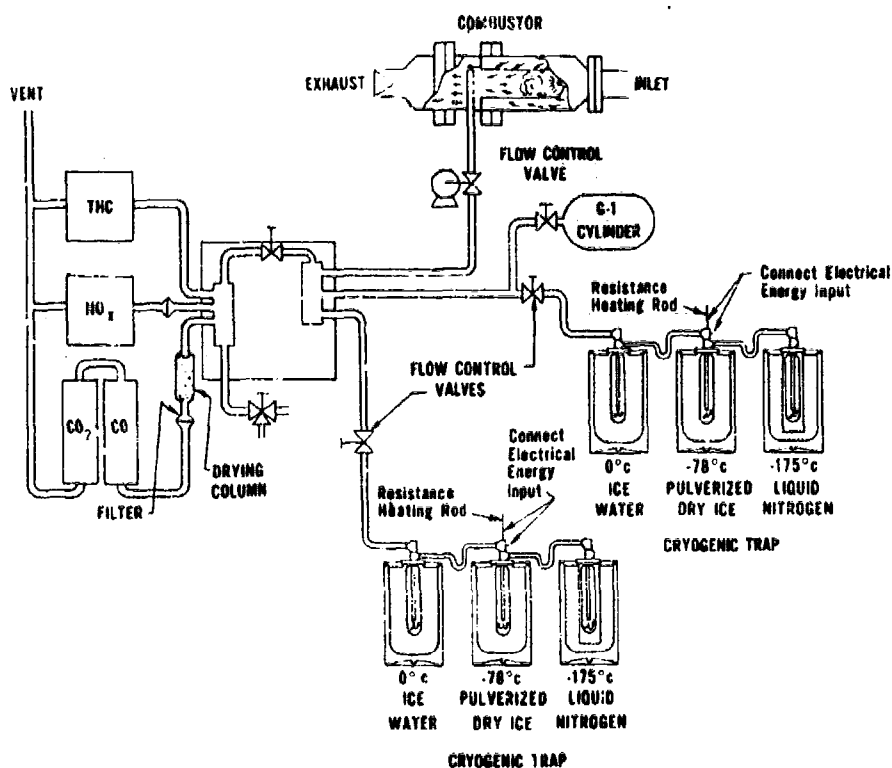

Figure 2. Sampling schematic system.

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Analysis

Hydrocarbon analysis of both the pressurized tank and online cryogenic samples was done with a coupled gas chromatograph (Varian model 1400) - mass spectrometer (Dupont model 21-491) - data (Dupont 21-094) system (Fig. 3). The chromatographic column packing was Porapak Q (120-150 mesh), in a 3-m-long by 1.6-mm-diameter microbore (0.7 mm) stainless steel tube. This column, with temperature programming, has proven adequate for separating hydrocarbon compounds ranging from ethane to C_{10} aliphatic and aromatic oxygenates. The chromatographic effluent was split 25% to the chromatographic flame ionization detector (FID), and 75% to the mass spectrometer for sample enrichment via jet separator. Compound quantitation was done by digital integration (Autolab IV) of the chromatograph-FID peak areas. All quantitation of the FID was based on benzene response; i.e., calibration was done with standard gas mixtures of known benzene concentration. Compound identification was done by the MS-data system, based on the data library comparison of fracture patterns (5).

Figure 3. Laboratory analytical system; coupled gas chromatograph-mass spectrometer-data system used for analysis of hydrocarbon compounds in turbine engine exhaust.

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The extremely low concentration of hydrocarbon in both cryogenic samples, and particularly in the grab samples, necessitated a laboratory concentration procedure that involved expanding the collected sample through a GC sample loop (2.9 ml) at liquid nitrogen temperature (-196°C). Heating the cryogenic sample bottle to a wall temperature of 150°C made the concentration procedure more effective.

The chromatographic analysis was done by temperature programming in two stages. Before injection, the gas chromatograph was cooled to -100°C. After injection, the air peaks were permitted to clear the column, and the oven temperature was raised to 0°C at approximately 10°C/min. The gas chromatograph was then instrumentally programmed at 10°C/min to a final temperature of 250°C. A terminal isothermal hold was maintained until no additional peaks eluted from the column. The chromatographic carrier gas was helium at a flow rate of 30 cm^3/min. The flow rates of air and hydrogen were 350 and 30 cm^3/min respectively.

RESULTS AND DISCUSSION

Effects of Fuel Type

Table 3 lists the exhaust hydrocarbon concentrations detected with JP4, JP5, and JP8 fuel, at a constant inlet pressure of 33 psig. Between the three fuels, several differences were noted in both total hydrocarbon content and compound distribution. Compared to JP4, the total concentration of exhaust hydrocarbon was greater with JP5 and JP8, which appeared to show a relationship between exhaust content and fuel density and/or boiling range (JP5 and 8 are higher boiling and density fuels than JP4). The greatest amount of hydrocarbon (5.07 ppm) was obtained with JP5, which has the highest density of the three fuels.

The qualitative differences between the fuels were primarily in the olefins and ketones, with lesser shifts in the paraffins, aromatics, ethers, and aldehydes. Overall, the olefins and ketones increased with fuel number, suggesting again a relationship between these compounds and fuel density and/or boiling range. These increases in olefins and ketones were offset somewhat by a decrease in the paraffin and aromatic content although no dramatic change occurred in the concentration of any particular compound. The maximum concentration of both ethers and aldehydes occurred with JP5 fuel, which indicated a trend toward imcomplete combustion with the higher density fuels. The mean molecular weight showed an increasing trend (with fuel number) for the napthenes, aromatics, and aldehydes, and no discernible difference for the other compound classes.

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TABLE 3. EXHAUST HYDROCARBON CONCENTRATION WITH VARIOUS FUELS
(33 psig combustor pressure)

COMPOUND (ppm)	JP4[a]	JP4[a]	JP5	JP8	NONE[b]
PARAFFINS	.83[c]	.88	.18	.07	0
Methane	.01	.02	.1	.01	
n-Butane				t[d]	
2,2,3-Trimethylbutane	.05				
2,4-Dimethylpentane			t		
3-Methylhexane	.13	.19			
2,3,4-Trimethylpentane	.02				
3,4-Dimethylhexane	.02	.09			
4-Methylheptane				t	
3,3-Dimethylhexane				.06	
2,4-Dimethylhexane	.09	.22	.04		
3,4-Dimethylheptane	.11				
n-Octane		.13			
Unknown			t		
n-Nonane	.05				
4-Methyloctane		.13			
2-Methyl-4-ethylhexane	.11	.04			
Unknown	.07		.03		
2-Methylnonane			.01		
Unknown	.04				
n-Decane	.04	.03			
2-Methyl-5-ethylheptane	.04	.02		t	
3,3,5-Trimethylheptane				t	
Unknown	.02				
Unknown	.03				
Unknown	t				
Avg molecular wt (paraffins)	124.3	107.83	155.92	98.16	
OLEFINS	.76	.76	1.52	1.71	0
Ethylene	.01	.01	.03	.09	
Acetylene	.02	.01	t	.02	
Propylene	.36	.44	.62	.65	
Propyne	.01	.01	t	.02	
2-Methylpropene	.02	.01		t	
1-Butene	.13	.14	.16	.19	
2-Butyne				t	
2-Butene-cis	.01				
1-Pentene			.43	.43	
2-Methyl-1-pentene		.12			
1-Hexene	.15				
Unknown		.02			
3-Heptene-trans	.02				
2-Methyl-3-Hexene-trans	t				
1-Heptene			.08		
2,3-Dimethyl-2-butene				.06	
1-Octene			t	.24	
1-Nonene				.01	
Unknown	.03				
Avg molecular wt (olefins)	65.93	52.11	59.11	63.2	

[a] Duplicate combustor conditions
[b] Background sample (no fuel)
[c] Total by chemical class
[d] Trace, concentration less than 0.001 ppm

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TABLE 3. (CONTINUED)

COMPOUND (ppm)	JP4[a]	JP4[a]	FUEL JP5	JP8	room[b]
DIOLEFINS	.10[c]	.01	t[d]	.02	0
Allene	.01	.01	t	.02	
1,3-Butadiene	t	t	t		
Unknown	.09				
1,2-Pentadiene		t			
2,3-Pentadiene				t	
1,3-Pentadiene-cis			t		
Avg molecular wt (diolefins)	59.72	54.07	54.07	54.06	
NAPHTHENES	t	.09	.20	.02	0
Cyclobutane		t			
Isopropylcyclopropane		.02			
1,2-Dimethylcyclopropane-cis	t				
Cyclohexane			.19	.01	
Methylcyclohexane		.07			
1-Methyl-2-ethylcyclopentane-cis			.01		
1,1,2-Trimethylcyclohexane				.01	
Avg molecular wt (naphthenes)	70.07	79.46	98.14	105.2	
AROMATICS	.43	.37	.28	.10	0
Unknown			.02		
Ethylbenzene	.15	.06			
1,3-Dimethylbenzene			.06		
1,4-Dimethylbenzene	.17	.17	.11	.10	
1,2-Dimethylbenzene			.05		
1,2,3-Trimethylbenzene		.04			
n-Propylbenzene	.08	.04		t	
m-Ethyltoluene			.03		
1,2,4-Trimethylbenzene		.04			
Unknown				t	
1,3-Diethylbenzene	.03	.02	.01		
Avg molecular wt (aromatics)	106.33	109.79	112.78	116.22	
ALDEHYDES	.62	.81	2.72	1.59	0
Acetaldehyde	.58	.59	2.07	1.01	
Acrolein			.09	t	
Propionaldehyde	.02	.16	.28	.31	
Crotonaldehyde		.05	.12		
Butyraldehyde	.02	.01	.14	.14	
2-Methylpentanal			.02	.08	
Unknown			t		
n-Hexanal	t				
Benzaldehyde			t	.01	
2,4-Dimethylpentanal				.04	
Avg molecular wt (aldehydes)	68.59	61.06	77.84	78.95	
ALCOHOLS	.06	.14	.03	.33	.09
Methanol	t	t		t	
Unknown	t				
Unknown	.05				.09
Unknown	t				
Cyclohexanemethanol	.01				
Isooctylalcohol			.03		
Unknown				.33	
2-Propylheptanol		.14		t	
Avg molecular wt (alcohols)	107.74	95.09	130.13	116.16	

[a] duplicate combustor conditions
[b] background sample (no fuel)
[c] Total by chemical class
[d] Trace, concentration less than 0.001 ppm

TABLE 3. (CONTINUED)

COMPOUND (ppm)	JP4[a]	JP4[a]	FUEL 704	JP8	ACDO[b]
KETONES	.23[c]	.77	.11	.46	.02
2-Butanone	.07	.09	.19	.35	
Unknown	.02	.01			
Methylpropylketone	.1				
2-Pentanone			.17		
3-Hexanone	.04		.02		
3-Methyl-2-pentanone				.01	
5-Methyl-2-hexanone	.10				
4-Methylcyclohexanone				.01	
4-Methyl-3-pentene-2-one					.02
Propylbenzylketone		.17		.03	
Unknown				.01	
3-Heptanone	t				
Unknown	.04				
Avg molecular wt (ketones)	100.88	108.59	79.11	111.11	
ETHERS	.25	.04	.15	.02	0
Furan	.0	.01	.09	.02	
2-Methylfuran					
3-Methylfuran	.2	t			
2,3-Epoxybutane					
Isooctyl vinyl ether		.01			
Avg molecular wt (ethers)	74.07	94.50	74.07	70.06	
ESTERS	0	.12	t	0	0
n-Amyl acetate		.12			
Unknown			t		
Unknown			t		
Avg molecular wt (esters)		130.12	246.17		
NITROGEN-CONTAINING COMPOUNDS	.05	0	.01	t	0
n-Valeronitrile			t		
Nitromethane	.01		.01	t	
Imidazole	.04				
Avg molecular wt (nitrogen)	64.56		72.06	61.04	
HALOGEN-CONTAINING COMPOUNDS	.05	.34	.01	.01	0
1-Fluorohexane	.04	.06			
Trichloroethylene	.01	.01	t	.01	
1-Fluoroheptane			.01		
Unknown		.004			
Unknown		.04			
1-Chloro-3-methylbutane		.19		t	
Avg molecular wt (halogen)	117.5	149.97	154.76	118.52	
LACTONE	0	0	.01	.01	0
B,B-Dimethylpropiolactone			.01	.01	
Avg molecular wt (lactone)			100.05	100.05	
TOTAL OF ALL HYDROCARBONS	3.17	3.87	5.27	4.41	0.11

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[a]Duplicate combustor conditions
[b]Background sample (no fuel)

[c]Total by chemical class
[d]Trace, concentration less than 0.001 ppm

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Effects of Operating Pressure

Table 4 lists the exhaust hydrocarbon concentrations as a function of combustor operating pressure for JP4 fuel. As expected, the overwhelming effect of increasing pressure was a large reduction in the exhaust total hydrocarbon content (approximately 6-fold for each factor of 2.2 increase in operating pressure). This was almost certainly a direct result of improved combustion efficiency, which obtained from increased combustion temperature as well as operating pressure.

Although inlet pressure had a significant effect on the quantity of exhaust hydrocarbon, there were only minor changes in exhaust quality. As a percentage of total hydrocarbons, increased operating pressure resulted in increased olefinic content primarily at the expense of paraffins. The maximum percentage of partially oxygenated species occurred in the mid pressure range, from 33 to 50 psig, but was greatly reduced at 75 psig, reflecting the greatest degree of oxidative completion. The mean molecular weight of nearly all classes of exhaust hydrocarbon species tended to increase with operating pressure.

Toxicological Implications

Perhaps the most significant aspect of the data, from the toxicological point of view, was the large number of individual compounds detected in turbine engine exhaust. About 150 compounds were identified in the 8 cryogenically collected exhaust samples, with a mean of 38 compounds per sample. Approximately half the compounds were paraffins, napthenes, olefins and diolefins which, in general, would be less toxic than many of the aromatic and oxygenated species. The overall trend toward higher molecular weight compounds and more oxygenates with increasing fuel density portend a potentially more toxic exhaust with heavier fuels. The finding of B, B-dimethylpropiolactone in the exhaust of JP5 and JP8 was perhaps significant in that this compound is a close analog of B-propiolactone, one of the 13 known carcinogens restricted by the Occupational Safety and Health Administration (6). However, detailed analysis of the full toxicological impact of turbine engines' exhaust hydrocarbon will have to be delayed until data from a broader spectrum of engines and operating conditions are available.

Reproducibility

A major accomplishment of this test series was the excellent demonstration of reproducibility between duplicate cryogenic samples. The two samples in question were taken at an operating pressure of 33 psig with JP4 fuel (Table 3). Total hydrocarbon recovery was 3.17 and 3.87 ppm, respectively. Within hydrocarbon compound classes, the concentration reproducibility was on the average plus or minus 0.05 ppm. The total number of compounds detected in the two samples was 58 and 50, respectively, with over 55% commonality of individual compounds.

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TABLE 4. EXHAUST HYDROCARBON COMPOUNDS FOR JP4 FUEL AT VARIOUS INLET PRESSURES

	COMBUSTOR INLET PRESSURE (psig)				
COMPOUND (ppm)	15	33[a]	33[a]	50	75
PARAFFINS	11.87[b]	.88	.83	.23	.16
Methane	.02	.02	.01	.01	.01
1,1-Didevteroethane				t[c]	
n-Butane	t				
n-Pentane	t				
2-Methylpentane	.51				.04
2,3-Dimethylbutane				.01	
Unknown	t				
3-Methylpentane					.06
2,2,3-Trimethylbutane			.05		
3-Methylhexane	1.22	.19	.13		
2,3-Dimethylpentane					.01
2,3,4-Trimethylpentane			.02		
3,4-Dimethylhexane	.56	.09	.02		
2,4-Dimethylhexane	1.70	.22	.09	.02	
3,4-Dimethylheptane			.11		
2,4,4-Trimethylhexane				.05	
n-Octane	4.91	.13		.03	.01
2,6-Dimethylheptane	.78			.02	
n-Nonane	.84		.05	.03	.01
4-Methyloctane	1.01	.14			
3-Methyloctane				t	
2-Methyl-4-ethylhexane		.04	.11	.02	
3,3-Dimethylhexane					.01
Unknown			.07		
2-Methylnonane	.20				
2,2,5-Trimethylhexane				.02	
Unknown			.04		
n-Decane		.03	.04		
Unknown				.02	
2-Methyl-5-ethylheptane		.02	.04		
3,3,5-Trimethylheptane	.12			t	.01
Unknown			.02		
Unknown			.03		
Avg molecular wt (paraffins)	98.43	107.83	124.3	113.65	94.56
OLEFINS	3.80	.76	.76	.17	.28
Ethylene	.24	.01	.01	.01	.01
Acetylene	.28	.01	.02		.05
Propylene	1.35	.44	.36	.11	.13
Propyne	.05	.01	.01		
2-Methylpropene	.09	.01	.02		.01
1-Butene	.60	.14	.13	.05	.08
2-Butyne	t				
2-Butene-cis			.01		t
2-Pentene-cis	.64				
2-Methyl-1-pentene		.12			
1-Hexene			.15		
4-Methyl-1-Hexene	.55				
Unknown		.02			
3-Heptene-trans			.02		
2-Methyl-3-Hexene-trans			t		
Dipentene				t	
Unknown			.03		
Avg molecular wt (olefins)	52.30	52.11	65.93	65.62	44.08

[a]Duplicate combustor conditions
[b]Total concentration by chemical class
[c]Trace, concentration less than 0.001 ppm

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TABLE 4. (CONTINUED)

COMPOUND (ppm)	COMBUSTOR INLET PRESSURE (psig)				
	15	33[a]	33[a]	50	75
DIOLEFINS	.05[b]	.01	.10	.02	t[c]
Allene	.05	.01	.01		
2,3-Butadiene	t	t	t		
Unknown			.09		
1,2-Pentadiene		t		.02	t
Avg molecular wt (diolefins)	54.07	54.07	59.72	68.06	68.06
NAPHTHENES	.53	.09	t	.05	.01
Cyclobutane		t			
Isopropylcyclopropane		.02			
1,2-Dimethylcyclopropane-cis			t		
Unknown				t	
Methylcyclohexane	.53	.07		.05	.01
Avg molecular wt (naphthenes)	98.19	79.46	70.07	84.14	98.19
AROMATICS	1.43	.37	.43	.04	.08
Ethylbenzene		.06	.15		
1,3-Dimethylbenzene					.01
1,4-Dimethylbenzene	.81	.17	.17	.02	
1,2,3-Trimethylbenzene	.53	.04			
n-Propylbenzene		.04	.08		
p-Ethyltoluene				.02	
1,2,4-Trimethylbenzene		.04			
Unknown	.09				
1-Methyl-2-Ethylbenzene					.06
1,3-Diethylbenzene		.02	.03		.01
Avg molecular wt (aromatics)	116.2	109.79	106.33	99.4	106.34
ALDEHYDES	3.55	.81	.62	.17	.04
Acetaldehyde	2.3	.59	.58	.16	.01
Acrolein	t			t	
Propionaldehyde	.61	.16	.02	t	t
Crotonaldehyde	.23	.05		.01	t
Butyraldehyde	.36	.01	.02	t	t
2-Methylpentanal	.05			t	t
n-Pentanal				t	
Unknown	t				
n-Hexanal			t		
n-Heptanal				t	t
Benzaldehyde				t	.03
Avg molecular wt (aldehydes)	73.53	61.06	68.59	75.84	77.43
ALCOHOLS	.43	.14	.06	0	t
Methanol	t	t	t		
Unknown			t		
Unknown			.05		
Unknown			t		
Cyclohexanemethanol			.01		
2-Propylheptanol		.14			
2-Butyl-1-octanol	.43				t
Avg molecular wt (alcohols)	109.11	95.09	107.74		158.16

[a]Duplicate combustor conditions
[b]Total concentration by chemical class
[c]Trace, concentration less than 0.001 ppm

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TABLE 4. (CONTINUED)

	COMBUSTOR INLET PRESSURE (psig)				
COMPOUND (ppm)	15	33[a]	33[a]	50	75
KETONES	.62[b]	.27	.22	t[c]	t
2-Butanone	.62	.09	.02	t	t
Unknown		.01	.02		
Methylpropylketone			t		
3-Hexanone			.04		
Unknown					t
5-Methyl-2-hexanone			.10		
Propylbenzylketone		.17			
Unknown					t
3-Heptanone			t		
Unknown			.04		
Avg molecular wt (ketones)	65.07	108.59	100.88	65.07	76.09
ETHERS	.15	.08	.05	.02	t
Furan	.14	.03	.02	.02	
2-Methylfuran	.01	t			
3-Methylfuran			t		
2,3-Epoxybutane		.04	.03		t
Isooctyl vinyl ether		.01			
Avg molecular wt (ethers)	75.09	94.59	74.08	68.07	72.05
ESTERS	0	.12	0	0	.02
n-Amyl-acetate		.12			
Heptyl formate					.01
Unknown					.01
Unknown					t
Avg molecular wt (esters)		130.18			212.15
NITROGEN-CONTAINING COMPOUNDS	0	0	.05	t	0
Nitromethane			.01		
Unknown				t	
Imidazole			.04		
Avg molecular wt (nitrogen)			64.56	99.06	
HALOGEN-CONTAINING COMPOUNDS	.62	.34	.05	.03	t
Unknown				t	
Chloroethylene	t			t	t
1-Fluorohexane		.06	.04		
Trichloroethylene	t	.01	.01	t	t
Unknown				.03	
Amyl-2,2-dichloropropionate	.62				
Unknown		.04			
Unknown		.04			
1-Chloro-3-methylbutane		.19			
Avg molecular wt (halogen)	135.31	149.97	117.75	90.63	96.95
LACTONE	0	0	0	.01	0
2,2-Dimethylpropiolactone				.01	
Avg molecular wt (lactone)				100.05	
TOTAL HYDROCARBON CONTENT	23.05	3.87	3.17	0.74	0.59

[a] Duplicate combustor conditions
[b] Total concentration by chemical class
[c] Trace, concentration less than 0.001 ppm

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SUMMARY AND CONCLUSIONS

Cryogenic sampling was used to sample hydrocarbon exhaust from a T-56 turbine engine combustor under conditions simulating the idle power setting of several different Air Force inventory aircraft. The parameters studied were fuel type (JP4, JP5, and JP8) and combustor operating pressure (15, 33, 50, and 75 psig). The principal conclusions from the study were:

1. Cryogenic sampling was an effective and reproducible technique for sampling gaseous hydrocarbon exhausts from turbine engines.

2. The hydrocarbon content of combustor exhaust was inversely related to operating pressure.

3. The hydrocarbon content was directly related to fuel density and/or boiling point.

4. About 150 compounds were identified; of these approximately half were aromatic and oxygenated species.

5. A trend toward higher molecular weight compounds and more oxygenates with increasing fuel density suggested a more toxic exhaust with heavier fuels.

6. Duplicate samples demonstrated excellent reproducibility, with a concentration variation on the average of 0.05 ppm.

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